ECLOGITES IN CALIFORNIA.[1]

CONTENTS.

THE term "eclogite" was first introduced into the geological literature of Europe in 1822 by Haüy in his *Traité de mineralogie*, in which he gave the name to a rock composed chiefly of green augite and garnets. In the present paper the name is applied to a rock derived from some eruptive and bearing garnets in a matrix composed essentially of some form of augite, or of hornblende, or of both augite and hornblende. The various secondary minerals are given in the descriptions that follow. The term eclogite has proved useful, and the rock has evidently been an interesting one to European petrographers, for as far back as 1884 Lohmann[2] gives two pages of bibliography as an introduction to his paper on eclogites. Since then many articles have appeared in English and continental journals, the most recent being the excellent paper by Hezner,[3] which gives a discussion of the petrographical relations of eclogites and amphibolites found in the Tyrol Alps, with a bibliography of over seventy references. Hezner's article was received after the present paper was written, and although some few extracts from it have been inserted, the special student of these rocks is referred to the original article for the full details of this important contribution to the subject.

[1] The writer is under obligations to Dr. J. P. Smith, of Stanford University, for suggestions and advice.

[2] "Neue Beiträge zur Kenntniss des Eklogits vom mikroskopischen, mineralogischen und archäologischen Standpunkt," *Neues Jahrbuch für Mineralogie, Geologie und Paleontologie*, Vol. I (1884).

[3] "Ein Beitrag zur Kenntnis der Eklogite und Amphibolite," Tschermak. Mineralogisch-petrographische *Mitteilungen*, Vol. XXII (1903).

Hitherto, so far as known to the writer, no rocks have been described in the country under the title of eclogites. Nutter and Barber[1] refer to them incidentally in their discussion of glaucophane schists, and Diller[2] has recently included some rocks of the eclogite type in his description of the amphibole schists of Port Orford, Ore., but without designating them by this term. A brief preliminary review of the eclogites of Europe will furnish a basis for comparison in the study of those of our west coast.

EUROPEAN ECLOGITES.

The type eclogite of Europe is described in the valuable paper of Lüdecke,[3] who gives a detailed account of the chief minerals and of a dozen rocks found in the island of Syra. Of these latter he places glaucophane eclogite as the most important. This consists of red garnets, light green omphacite, and glaucophane. He mentions muscovite, quartz, and pyrite as accessory minerals. The omphacite is a light green augite appearing in grains and in small columns, sometimes showing the augite cleavage. Under the microscope there is little or no pleochroism, bright polarization, and a high extinction angle. The garnets are rhombic dodecahedrons with rounded corners. The glaucophane is the same as that so common on the Pacific coast, and which will be described more fully later. The garnet is considered the oldest mineral; younger than that is placed glaucophane and omphacite; and youngest of all, the quartz. In the laboratory at Stanford University are small specimens of the Syra eclogite—obtained through the kindness of Mr. Diller—which very much resemble some facies of the glaucophane eclogite of Tiburon. The glaucophane is a trifle darker blue, and the garnets do not show such definite crystal forms as do those in the California rock. In his general description of eclogites Lohmann reports the occurrence of the rock in Norway, Switzerland, Austria, France, Italy, Greece, and South Africa. Lohmann's paper is mainly devoted to an account

[1] "On Some Glaucophane and Associated Schists," JOURNAL OF GEOLOGY, Vol. X, p. 738.

[2] Folio No. 89, *Geological Atlas of the United States.*

[3] "Der Glaucophane und die glaucophane-führende Gesteine der Insel Syra," *Zeitschrift der Deutschen Geologischen Gesellschaft*, Vol. XXVII (1876).

of the stone axes made from eclogites, but his bibliography and his summaries of previous geological descriptions are of great value to the petrographer. Teall[1] describes an eclogite from the British Isles. This rock has a dull green color with reddish-brown garnets. The groundmass is omphacite with intergrowths of hornblende, feldspar, and rutile—rarely with quartz and epidote. The hornblende is strongly pleochroic. The color of the **c** ray is bluish-green; **b**, deep rich green; **a**, pale yellowish-brown. Bonney,[2] under a subheading of igneous rocks, describes a massive hornblende rock that appears to be a diorite and contains many small garnets with sphene, quartz, plagioclase, and zircon as probable accessories. He concludes that the rock might be termed a hornblende eclogite.

Patton[3] describes a "Kelyphite eclogite" from Bohemia in which the garnets are surrounded by a ring or mantle usually of hornblende and feldspar. The groundmass is a complex of hornblende and pyroxene crystals. Another outcrop with striated feldspar in the groundmass he calls, not eclogite, but an eclogite-like rock. With the disappearance of the omphacite and garnets and of the kelyphite ring the structure becomes more schistose and the rock passes into ordinary hornblende schist.

The eclogites of Bavaria are described by Newland[4] as forming a series of hills extending for some fifteen miles in the Bavarian mountains. He finds that the eclogite grades over into a basic gneiss of hornblende, garnets, and feldspar, but not into the more acid gneiss. The eclogite consists essentially of omphacite, hornblende, and garnets, with the usual accessory minerals. The analyses which he gives of Bavarian eclogites are quoted later.

Traube[5] describes an eclogite in Silesia occurring with gabbro, amphibolite, and serpentine, and forming bands separated by serpen-

[1] "On an Ecolgite from Loch Duich," *Mineralogical Magazine*, Vol. IX, p. 217.

[2] "Notes on the Vicinity of the Upper Part of Loch Maree," *Quarterly Journal of the Geological Society*, Vol. XXXVI (1880), p. 105.

[3] "Die Serpentin-und Amphibole-Gesteine nördlich von Marienbad in Böhmen," *Tscherm. min.-petr. Mitth.*, Vol. IX (1887), p. 89.

[4] "Notes on the Eclogite of the Bavarian Fichtel-Gebirge," *Transactions of the New York Academy of Science*, Vol. XVI, p. 24.

[5] "Ueber ein Vorkommen von Eklogite in Schlesien," *Neues Jahrbuch*, Vol. I (1889), p. 195.

tine. The eclogite from the Tyrol Alps recently described by Hezner[1] is composed primarily of clear red garnets, commonly in rounded grains, in a groundmass of emerald-green omphacite. The garnets vary from fine grains up to the size of peas, but the crystal form is seldom distinct. Hezner considers that this eclogite is chemically a gabbro or a variation of the same magma that furnished the gabbro. Eclogite, he thinks, is formed in the greatest depths and in the higher zones amphibolite—the garnet and the omphacite being amphibolized.

The foregoing brief extracts will give some idea of the eclogites of Europe and of their probable derivation.

CALIFORNIA ECLOGITES.

Probably the most typical eclogite in California is that found in the bed of Coyote Creek, about eighteen miles southeast of San José and some six miles east of north from San Martin. The outcrop of massive rock is exposed for about twenty feet in the edge of the stream. Apparently it breaks through the shale and jasper exposed at the foot of the hill only a few feet away, but the gravel of the creek entirely covers the contact. On the opposite side of the stream, and within a hundred yards, is a large mass of serpentine, which, however, is not in contact with the eclogite. The most characteristic facies of the outcrop is that which shows a grass-green groundmass, thickly studded with dark red garnets several millimeters in diameter and showing distinctly the rhombic dodecahedron form. The faces of the garnet are fresh and shining, with clear-cut edges. The reproduction of the photograph in Fig. 1 shows the structure of the rock, but the striking effect of the red garnets in the light green groundmass is unfortunately lost.

Seams and segregations of glaucophane, sometimes bearing garnets, occur in the exposure. Prominent veins of a fine-grained reddish mineral were taken in the field for inclusions of the nearby jasper, but its fusibility, and its isotropic character under the microscope, proved it to be a compact variety of garnet. Segregations of actinolite crystals are common, and chlorite frequently occurs. Some particles of chalcopyrite are seen in the rock, and a few parti-

[1] *Op. ci*

cles of free gold were found in the granular garnet. The rock has attracted the attention of prospectors, and it is reported that an assay showed nearly two dollars of gold per ton. In a few places there were inclusions, some 10–15^{mm} in diameter, of a reddish-brown mineral with cleavage faces giving an almost metallic luster. In the laboratory the mineral was found to be infusible and to possess a hardness

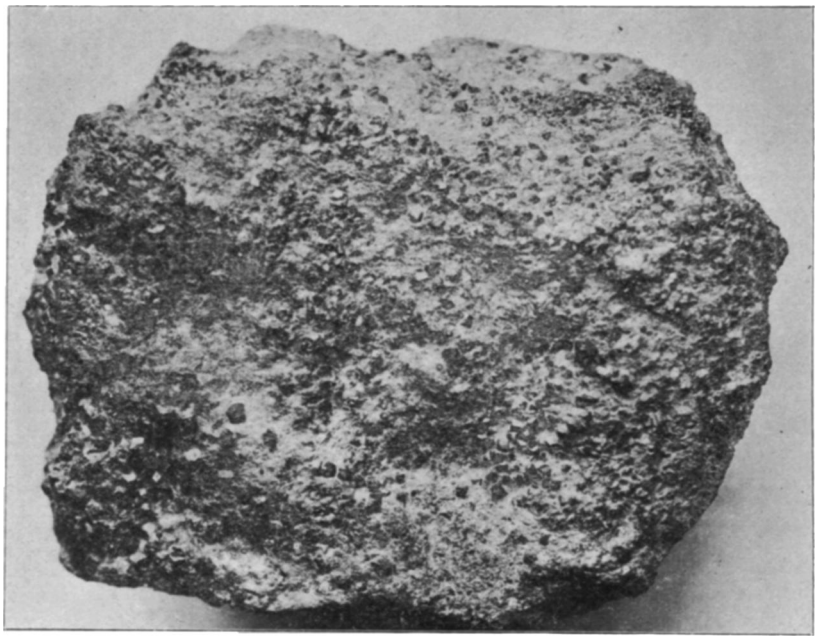

FIG. 1.—Eclogite from San Martin, Calif. Slightly reduced in size.

of over six. The streak is yellowish-brown. A determination of the specific gravity of the purest fragment obtainable gave a result of 4.154. After fusion with soda the acid solution boiled with tin gives the violet reaction of titanium. The mineral was determined as rutile—a result which the microscopic examination of a thin section confirmed.

The specific gravity of the eclogite itself varied from 3.33 to 3.58 in different fragments—apparently varying with the number of garnets included. Some of the garnets were separated from the groundmass and found to have a specific gravity of 3.68. A qualitative determi-

nation of the garnets indicates that they are the iron-alumina variety with a considerable amount of calcium.

Under the microscope the main groundmass of the eclogite is seen to be light-green omphacite, with little, if any, pleochroism. The interference colors are bright, and the extinction angle runs up to 40°. The garnets show regular outlines, and are of a pale pink color by transmitted light. Usually they are cracked, with omphacite filling the cracks. Rutile is present as a segregation in the groundmass and as inclusions in the garnets. Sphene of a light brownish color, somewhat pleochroic, and with characteristic relief, is plentifully distributed in irregular grains.

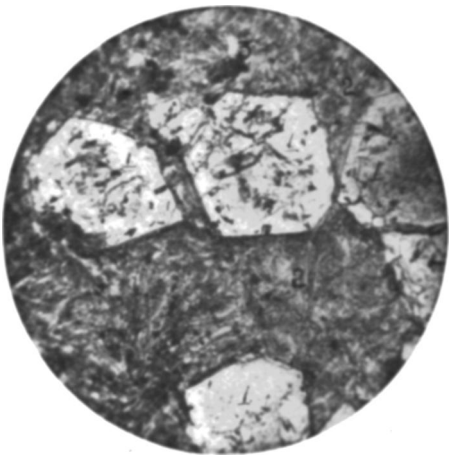

FIG. 2.—Omphacite eclogite, San Martin. × 24. 1 = garnet, 2 = omphacite, 3 = rutile.

The microphotograph in Fig. 2 shows the clear outlines of the garnets. The inclusions in them are omphacite, apatite, rutile, quartz, and sometimes chlorite. The felted groundmass is composed of small columns of omphacite. Many of the slides are practically free from glaucophane, although veins of this mineral are quite plentiful in the exposure. The glaucophane is a somewhat more definite blue than is usually described as steel-blue, and in the slide shows strong pleochroism. The color of the **a** ray is a very pale yellow; the **b** ray, a purplish violet; the **c** ray, a clear blue. The extinction angles in several sections were found to be close to 5°. The orientation is that common in glaucophane, with the **b** axis corresponding to the axis of symmetry and the **c** axis nearest to *c'*. In places the glaucophane grades over into a green hornblende. In one of the slides there is an irregular-shaped mineral of a light brown color and cut by intersecting cracks. It is pleochroic in tints of brown. The relief is high, and the interference colors are of the third or fourth

order. While this mineral differs somewhat from the sphene appearing in grains, it is thought to be the same, although possibly somewhat changed by decomposition.

Calaveras Valley.—This little valley is in Santa Clara county, about fifteen miles northwest from the Lick Observatory. In it are found two distinct kinds of eclogite—a light-green omphacite variety and a dark, almost black, hornblende eclogite. The first occurs at the mouth of the narrow gorge which is the outlet of the valley to the north. The outcrop is on the west side of the stream on the bank of the flood-plain, and is about a hundred feet long. On the hillside above, serpentine is found, and in the stream-bed below, shale and sandstone, with characteristic Miocene fossils.

The dark hornblende eclogite is farther upstream on the east side of the valley. The exposure is over a hundred feet in thickness, and was followed southward for more than a half-mile without finding the limit. On the upper side is a greenstone with an extensive serpentine belt lying just above. Farther upstream sandstone occurs between the eclogite and the serpentine. The eclogite appears to be a dike cutting across the Franciscan sandstone.

The green eclogite of the lower exposure varies considerably in its appearance. The garnets are sometimes small and clear-cut, sometimes 8 to 10^{mm} in diameter and without definite form. Glaucophane is also very irregularly distributed throughout the exposure. Under the microscope the groundmass is seen to be largely composed of closely packed little columns of omphacite. Much of it shows wavy extinction, as if the rock had been subjected to crushing. This is also indicated by the badly fractured condition of the larger garnets. Part of the green groundmass is probably the grass-green hornblende, smaragdite, although rather indefinite results were obtained in measuring extinction angles. Irregular light-colored sphene granules are scattered freely through the slides. A mineral with lighter color than the omphacite shows some pleochroism and very low interference colors. It was determined as chlorite, and is probably derived from the hornblende or the augite. In places it shows a bright Prussian blue interference color—according to Rosenbusch, a characteristic of the pennine division of chlorites. Glaucophane is plentiful in some of the slides and in a few instances gave an

extinction angle as high as 15° for the angle of **c** on *c'*. Small quantities of feldspar and quartz appear in some of the slides.

The relations of the glaucophane and the chlorite are interesting, as seen in Fig. 3, where the two minerals are apparently reacting in some way. Along the line of contact there is a deep blue border as indicated in the sketch. In Fig. 4, which is from the same slide, the crystal of glaucophane cuts clearly through the chlorite. The latter has evidently been sheared by some stress, and the glaucophane is a later growth. The chlorite crystal has a definite extinction angle of

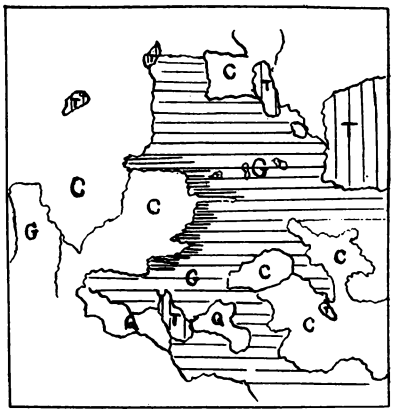

FIG. 3.

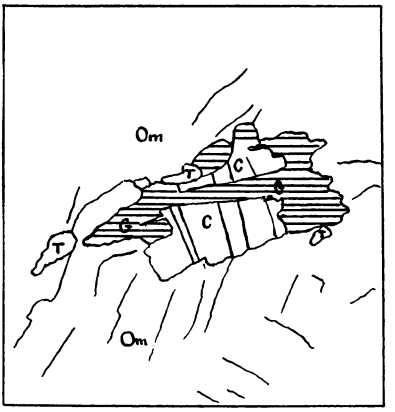

FIG. 4.

G = glaucophane, *C* = chlorite, *T* = sphene, *Q* = quartz, *Om* = omphacite

15°, which may indicate formation from hornblende, for the chlorite properly has small extinction angles or no definite extinction.

The dark hornblende eclogite in Calaveras Valley is the only one of its kind yet found in the state. Macroscopically it shows the dark hornblende with fresh cleavage faces, and with garnets plentiful in some specimens and few in others. Before the blowpipe the hornblende melts easily to a magnetic globule, at the same time coloring the flame yellow.

In the slide nearly all possible sections of the hornblende are found, as may be seen in the accompanying microphotograph. The garnets lack the clear outlines so noticeable in the San Martin eclogite. Some of the hornblende crystals are bordered with glaucophane, which appears white in the photograph. The hornblende

is strongly pleochroic as follows: **a**, light greenish-yellow; **b**, olive-green; **c**, greenish-blue. The orientation is the same as in glaucophane the **b** axis corresponding to the axis of symmetry and the extinction angle of **c** on *c'* is nearly 25°. This angle is unusually large for hornblende. Hintze,[1] however, gives some still greater. His table of extinction angles for hornblende varies from 16° to 27° 30′, the percentage of Al_2O_3 varying at the same time from 1.89 to 20.73. A black hornblende, pargasite, has an extinction angle, **c** on *c'*, of 24° 30′ the Al_2O_3 varying from 11.92 to 13.75 per cent. A light green pargasite is given with a slightly higher extinction angle, and also a higher percentage of alumina. The pleochroism is not given in the same table, but a few pages later he gives the following for a light pargasite: **a**, g eenish-yellow; **b**, emerald-green; **c**, greenish-blue. It should be noted that pargasite is sometimes blue and appears to be usually soda-bearing, as the analyses quoted by Hintze show.

FIG. 5. — Hornblende eclogite, Calaveras. × 24. 1 = garnet, 2 = quartz, 3 = hornblende, 4 = rutile, 5 = glaucophane.

Blasdale[2] describes a hornblende from the vicinity of Berkeley with a pleochroism of **c**, bluish-green; **b**, yellowish-green; **a**, lighter green. The extinction angle is given as 14° 34′, and the percentage of soda 2.45 and of alumina 2.05–3.45. The glaucophane in the Calaveras hornblende eclogite is along the borders of the hornblende crystals, and is apparently of a later growth. A similar instance of such a change is described by Cross,[3] who found blue hornblende upon the ends of a brown hornblende occurring near Silver Cliff, Colo.

[1] *Handbuch der Mineralogie*, Vol. II, p. 1188.

[2] "Contributions to Mineralogy," *Bulletin of the Department of Geology, University of California*, Vol. II, p. 328.

[3] "Some Secondary Minerals of the Amphibole and Pyroxene Groups," *American Journal of Science*, Vol. XXXIX (1890), p. 359.

The garnets in the hornblende eclogite have a fresh, clear color, and show little sign of change, but they are much cracked. Small quantities of feldspar and of quartz are found in the different slides. An opaque irregular mass shows by reflected light a yellow center and a black border. It is undoubtedly pyrite surrounded by iron oxide.

A hand specimen of eclogite has recently been sent to the writer by W. D. Smith, who collected it at a point some four miles south of east from the Calaveras exposure described in this paper. It carries coarse red garnets up to a half-inch in diameter, some of them showing well the rhombic dodecahedral form. The groundmass seems to be chlorite, glaucophane, and omphacite. The eclogite most resembles the San Martin variety, but is not quite so fresh in appearance. No igneous rock is reported from the vicinity.

Tiburon.—In addition to the interest attached to this locality because of the discovery of lawsonite, the peninsula of Tiburon in San Francisco Bay is noteworthy from the number of outcrops of eclogite found there. Much of the rocky knoll near Reed Station, where the lawsonite occurs, is eclogite of the glaucophane-omphacite variety. The minerals in this rock have been described by Ransome.[1] On the top of the hill above the lawsonite are two outcrops of eclogite occurring in the serpentine area. These have more omphacite than glaucophane, while on the slope of the hill beyond a glaucophane eclogite occurs that is almost free from omphacite. The slides from the first outcrop were mainly selected to show lawsonite, and so the proportion of that mineral appears unduly large. The matrix is usually composed of small allotromorphic crystals of a grass-green color intergrown with glaucophane. The green mineral shows no pleochroism in most cases. The extinction is frequently wavy, but where it admits of measurement the maximum angle is close to 40°. The mineral is identified as omphacite, with a probability that a portion of the green matrix is hornblende. In some cases the garnets are almost entirely replaced by chlorite; in others there is a celyphite border of the chlorite. In one instance the garnet has a celyphite border of mica. Mica is very common in these slides, and is determined as margasite by Ransome, to whom reference is made for the full description of the associated minerals.

[1] "On Lawsonite, a New Rock-Forming Mineral," *Bulletin of the Department of Geology, University of California*, Vol. I, p. 311.

San José.—The hills just south of the Oak Hill Cemetery are composed largely of masses of peridotite and gabbro with the resulting serpentine. On one slope there is an outcrop of grayish-green rock that is in part eclogite. The garnets are small and sometimes form veins of the compact granular variety of this mineral. In the slide there is much glaucophane and chlorite, the latter frequently exhibiting the Prussian blue interference color. A few crystals of feldspar are found, and also considerable mica and sphene. The outcrop is of interest mainly because of its occurrence in an area of igneous rocks.

Eclogites from other localities.—Slides and hand specimens from Sonoma county have been studied in the laboratory. They are of the glaucophane type of eclogite and have the usual accessories. Nutter and Barber[1] state that the eclogite occurs in large masses associated with schists. Melville[2] describes a bluish glaucophane schist from Mount Diablo with streaks of green and with innumerable garnets. No slide or hand specimen has been available. Among the rocks of Catalina Island, W. S. T. Smith[3] describes a garnet amphibole of greenish or brownish hornblende and carrying roughly rounded garnets. Rutile is mentioned as an inclusion. The term "eclogite" is not used in his account. A specimen of eclogite from Anacapa Island, some sixty miles to the northwest of Catalina, is in the Law collection, but there is no note as to its occurrence.

OREGON ECLOGITE.

Although the locality is outside of California, fuller reference should be made to the rocks described by Diller from Port Orford. He finds glaucophane-, actinolite-, mica-, and epidote-schists all grading into each other and all having the same origin. Garnets are sometimes found in abundance. These schists he thinks are derived from rocks of the basaltic type. In many places the original rock is changed to plagioclase hornblende rock. Usually the pyroxene alters to a green hornblende, but sometimes to a blue—giving the

[1] *Op. cit.*, p. 740.

[2] "Notes on the Chemistry of the Mount Diablo Rocks," *Bulletin of the Geological Society of America*, Vol. II, p. 403.

[3] "The Geology of Catalina Island," *Proceedings of the California Academy of Science*, Geology, 3d ser., Vol. I, p. 62.

glaucophane schist. While the alteration is generally complete, he found a volcanic neck where on one side the change is not entire, and under the microscope augite is seen changing into glaucophane. The feldspar has changed chiefly to epidote. Some green hornblende and chlorite are present. An examination of several slides—kindly loaned by Mr. Diller to Dr. J. P. Smith—shows that part of them may be classed as glaucophane eclogites. One specimen from Winston's Bridge is essentially glaucophane and garnets—the latter 2–3^{mm} in diameter. Mica, chlorite, sphene, and epidote are also present. An analysis of this rock without the garnets, as given by Washington,[1] is included in the table herewith.

CONCLUSION.

The question of the derivation of eclogites and of their place in the series of metamorphic rocks is both interesting and difficult. In the absence of direct proof for any special instance at hand opinions as to the igneous origin of a metamorphic rock should be given with due reservation. It seems to be well established that both igneous and sedimentary rocks sometimes grade into schistose forms that appear to be indistinguishable on first examination. From the evidence now at hand the writer would conclude that the San Martin and the Calaveras eclogites are derived from basic eruptives of the gabbro type. This derivation is indicated by their massive and irregular appearance in the field as well as by the general field relations.

The occurrence of the San José eclogite in the Oak Hill area of igneous rocks indicates that we have there merely the modification of a rock derived from the same magma as the basic eruptives that form the hills. The igneous origin of the San Martin eclogite is also indicated by the chemical analysis. As may be seen in the accompanying table, the silica is only slightly over 44 per cent.—which indicates derivation from some very basic eruptive. The percentage of silica is very close to that given by Hezner in the two analyses which he has made. Hezner thinks that his analyses show well the normal chemical composition of eclogites. The table of analyses here given should be supplemented by additional work on the California eclogites, but it is at least suggestive in the comparisons which it affords.

[1] "Study of the Glaucophane Schists," *American Journal of Science*, Vol. CLXI.

ANALYSES OF EGLOGITES AND RELATED ROCKS.

	1	2	3	4	5	6	7	8	9
SiO_2	44.15	44.06	46.26	57.10	55.00	48.81	46.07	46.88	41.20
Al_2O_3	10.18	17.63	14.45	11.66	13.54	16.25	15.35	19.16	15.40
Fe_2O_3	11.92	3.40	4.41	2.84	2.74	6.00	3.61	10.63	2.49
FeO	13.04	9.96	5.82	3.22	3.37	7.48	9.87		4.67
MgO	6.18	7.19	11.94	6.37	10.21	7.12	7.83	9.48	15.51
CaO	4.51	11.58	11.66	13.89	12.09	9.72	4.37	13.37	12.26
Na_2O	5.11	2.92	2.45	2.21	2.10	2.64	3.22	.....	3.44
K_2O	2.09	0.91	1.51	0.81	0.50	0.46	2.68	.....	2.49
H_2O +110°	0.95	0.17	.....	0.54	0.32	0.12	4.25	.....	1.31
H_2O −110°		0.12	1.10				0.16	.....	
CO_2	.....	.....	.....	.....	.....	.....	1.05	.....	.....
TiO_2	Tr	2.29	0.28	.....	.....	.....	1.63	0.18	0.43
MnO	.....	.....	.....	0.31	0.20	0.43	tr.	.....	Fl. 1.86
Total	99.31	100.23	99.93	98.86	100.27	99.03	100.09	99.67	.....

1. San Martin eclogite, Analysis by C. B. Allen (kindness of Dr. J. P. Smith).

2 and 3. Tyrol eclogites. L. Hezner.

4, 5, and 6. Bavarian eclogites quoted, by Newlands.

7. Glaucophane (eclogite?) from Oregon. Washington.

8. Gabbro. Oak Hill, San José. Analysis furnished Dr. J. C. Branner by U. S. Geological Survey.

9. Pargasite, steel-blue to black. Hintze.

The opinions of Diller, Bonney, and Traube as to the igneous origin of certain eclogites have already been quoted. Harker[1] gives a brief description of eclogites, and quotes Fouqué and Lévy as to a French hornblende eclogite that is "a local modification of a diorite."

In connection with the igneous origin of eclogites, the writer tried the experiment of fusing several specimens in a coke assay furnace. The crucibles were kept at the highest temperature of the furnace for about three hours, and then the drafts were closed and the whole allowed to cool slowly overnight. The eclogites fused easily to homogeneous lava like obsidian. Under the microscope this showed a practically uniform isotropic character. With a high power points showing double refraction were found scattered through the slide, but no detail could be made out.

A list of the constituent minerals found in California eclogites, and a brief mention of their properties as they are found in these rocks, will unify the preceding descriptions.

First among the essential minerals is garnet. The color is usually a dark red in the hand specimen. In size the garnets vary from 2 to 5^{mm}, for the well-developed dodecahedrons of the San Martin eclogite,

[1] *Petrology for Students*, 1887, p. 329.

to 10 or 12^{mm} for the rounded forms in some of the Calaveras exposures. Of the essential minerals garnet is evidently the oldest, for in the cracks are found glaucophane, omphacite, and hornblende. Yet these latter minerals are also found as inclusions together with rutile, apatite, feldspar, and quartz. Inclusions of glaucophane may be paramorphs of inclusions in the original matrix. Qualitative tests indicate that the garnets contain iron, calcium, and aluminum.

Omphacite, the light green augite, usually occurs in aggregates of prismatic crystals, some a $\frac{1}{2}^{mm}$ in length and without definite termination. The bright polarization, absence of pleochroism, high extinction angle, and occasional augite cleavage serve to distinguish it. Lüdecke deduced the formula (CaFe) SiO_3MgSiO_3 from his chemical analyses.

Smaragdite is an emerald-green actinolite that in the eclogites much resembles omphacite, being distinguished from it by the hornblende extinction angle and usually by pleochroism. The blue soda hornblende, glaucophane, has the marked pleochroism already given and an extinction angle of **c** on *c'* varying from 5 to 15°. It seems to be derived from hornblende in the eclogite in Calaveras Valley—at least the hornblende crystals are bordered by it. Diller has already been quoted as to the change of pyroxene to glaucophane in the Port Orford rocks, some of which are here classed as eclogites. The analyses of some of the igneous rocks considered show that they contain enough soda for this change to occur without the addition of elements from the outside. The hornblende in the Calaveras eclogite show soda in the qualitative test, and also has a general resemblance to glaucophane in its pleochroism and in its orientation. Hintze has already been quoted in regard to a black pargasite that seems to agree closely with the Calaveras variety of hornblende in pleochroism and extinction angle. This pargasite contains, according to his analysis, 3.44 per cent. of soda—which is more than the percentage of soda in the Port Orford glaucophane.

Both garnet and hornblende are found replaced by chlorite—pale green in color, and showing low interference colors except in the pennine variety, which shows Prussian blue between crossed nicols.

Mica seems to be absent from the Calaveras slides and is found in very small quantities in those from San Martin. In the Tiburon

eclogite margasite is very plentiful and has been fully described by Ransome, as already cited. White mica, probably paragonite, occurs in the San José eclogite and in that from Sonoma county.

Titanite, or sphene, is thickly distributed in some of the slides in very minute grains. It is a very light brown color and pleochroic in tints of that color. Rutile in large crystals 10–15^{mm} in diameter is found only at San Martin, but it is found somewhat less freely than sphene in the shape of small irregular grains in nearly all the slides. It is yellowish to reddish-brown and somewhat pleochroic, and has very high relief.

Epidote is rather irregular in its occurrence. When found, it exhibits lower interference colors than those usually described. Ransome[1] thinks that this is accounted for by a smaller proportion of iron, and that in chemical constitution the epidote may grade over into zoisite. Zoisite and cyanite were seldom found. Pyrite appears occasionally, but not so frequently as was expected from the description of the European eclogites.

All of the above minerals are possibly secondary in their occurrence in eclogites. The occasional feldspar and quartz may be the only minerals remaining unchanged from the original rock. The garnets and the epidote have probably taken up the line of the original feldspar, while the soda is to be found in the glaucophane or in the pargasite variety of hornblende.

While the use of the term "eclogite" is now fairly definite, there is still a question of some limitations in its application. In constitution the rock must contain garnets in a matrix of omphacite, glaucophane, or hornblende, or of some mixture of these minerals. Hezner evidently would insist that there must be omphacite, for even with about equal proportions of hornblende he drops the term "eclogite" and uses "eclogite-amphibolite." The common accessory minerals are sphene, rutile, epidote, apatite, zoisite, cyanite, feldspar, and quartz. While some metamorphosed sedimentary rocks approach eclogites in composition, the tendency seems to be to restrict the term to rocks that are clearly of igneous derivation.

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[1] *Op. cit*, p. 310.